

WHAT IS CLAIMED IS:

1. A photovoltaic apparatus comprising:

(a) a plurality of photoelectric conversion elements, each being of an approximately spherical shape and including a first semiconductor layer and a second semiconductor layer which is located outside the first semiconductor layer, for generating photoelectromotive force between the first and second semiconductor layers, the second semiconductor layer having an opening through which a portion of the first semiconductor layer is exposed; and

(b) a support including a first conductor, a second conductor, and an insulator disposed between the first and second conductors for electrically insulating the first and second conductors from each other, the support having a plurality of recesses which are arranged adjacent to each other and of which inside surfaces are constituted by the first conductor or a coating formed thereon, the photoelectric conversion elements being disposed in the respective recesses so that the photoelectric conversion elements are illuminated with light reflected by part of the first conductor or coating formed thereon which constitutes the recess, the first conductor being electrically connected to the second semiconductor layers of the photoelectric conversion elements, and the second conductor being electrically connected to the exposed portions of the first semiconductor layers.

2. The photovoltaic apparatus of claim 1, wherein the photoelectric conversion elements have an outer diameter of 0.5 mm to 2.0 mm.

3. The photovoltaic apparatus of claim 1, wherein the opening of the second semiconductor layer has a central angle θ_1 of 45° to 90° .

4. The photovoltaic apparatus of claim 1, wherein the recesses of the support have respective openings of a polygon of which ones adjacent to each other are continuous, each of the recesses narrows toward a bottom thereof, and the first semiconductor layer and second semiconductor layer of each of the photoelectric conversion elements are electrically connected to the second conductor and the first conductor, respectively, at the bottom or in a vicinity thereof of the recess.

5. The photovoltaic apparatus of claim 4, wherein the first conductor is provided with a circular first connection hole formed at the bottom or in a vicinity thereof of the recess and the insulator is provided with a circular second connection hole having a common axial line with the first connection hole, a portion of the photoelectric conversion element in a vicinity of the opening of the second semiconductor layer fits in the

first connection hole and an outer surface portion above the opening of the second semiconductor layer is electrically connected to an end face of the first connection hole of the first conductor or to a portion thereof in the vicinity of the end face, and the exposed portion of the first semiconductor layer of the photoelectric conversion element is electrically connected to the second conductor through the second connection hole.

6. The photovoltaic apparatus of claim 5, wherein
an outer diameter D1 of the photoelectric conversion elements,

an inner diameter D2 of the openings of the second semiconductor layers, and

an inner diameter D3 of the first connection holes, and

an inner diameter D4 of the second connection holes satisfy a relationship $D1 > D3 > D2 > D4$.

7. The photovoltaic apparatus of claim 1, wherein a light-gathering ratio x which equals to $S1/S2$ is selected to be in a range of 2 to 8, wherein S1 is an opening area of each of the recesses of the support and S2 is an area of a cross-section of the photoelectric conversion elements including a center thereof.

8. A photovoltaic apparatus comprising:

(a) a plurality of photoelectric conversion elements, each being of an approximately spherical shape and including a first semiconductor layer and a second semiconductor layer which is located outside the first semiconductor layer, for generating photoelectromotive force between the first and second semiconductor layers, the second semiconductor layer having an opening through which a portion of the first semiconductor layer is exposed; and

(b) a support including a first conductor, a second conductor, and an insulator disposed between the first and second conductors for electrically insulating the first and second conductors from each other, the support having a plurality of recesses which are arranged adjacent to each other and of which inside surfaces are constituted by the first conductor or a coating formed thereon, the photoelectric conversion elements being disposed in the respective recesses so that the photoelectric conversion elements are illuminated with light reflected by part of the first conductor or coating formed thereon which constitutes the recess, the first conductor being electrically connected to the second semiconductor layers of the photoelectric conversion elements, and the second conductor being electrically connected to the exposed portions of the first semiconductor layers,

wherein each of the photoelectric conversion elements

has an outer diameter of 0.5 mm to 2 mm, and a light-gathering ratio x which equals to $S1/S2$ is selected to be in a range of 2 to 8, wherein $S1$ is an opening area of each of the recesses of the support and $S2$ is an area of a cross-section of the photoelectric conversion elements including a center thereof.

9. A photovoltaic apparatus comprising:

(a) a plurality of photoelectric conversion elements, each being of an approximately spherical shape and including a first semiconductor layer and a second semiconductor layer which is located outside the first semiconductor layer, for generating photoelectromotive force between the first and second semiconductor layers, the second semiconductor layer having an opening through which a portion of the first semiconductor layer is exposed; and

(b) a support including a first conductor, a second conductor, and an insulator disposed between the first and second conductors for electrically insulating the first and second conductors from each other, the support having a plurality of recesses which are arranged adjacent to each other and of which inside surfaces are constituted by the first conductor or a coating formed thereon, the photoelectric conversion elements being disposed in the respective recesses so that the photoelectric conversion elements are illuminated with light reflected by part of the first conductor or coating formed thereon

which constitutes the recess, the first conductor being electrically connected to the second semiconductor layers of the photoelectric conversion elements, and the second conductor being electrically connected to the exposed portions of the first semiconductor layers,

wherein each of the photoelectric conversion elements has an outer diameter of 0.8 mm to 1.2 mm, and a light-gathering ratio x which equals to $S1/S2$ is selected to be in a range of 4 to 6, wherein $S1$ is an opening area of each of the recesses of the support and $S2$ is an area of a cross-section of the photoelectric conversion elements including a center thereof.

10. The photovoltaic apparatus of claim 1, wherein the photoelectric conversion elements have a pn junction in such a manner that the second semiconductor layer of one conductivity type having a wider optical band gap than the first semiconductor layer having the other conductivity type does is formed outside the first semiconductor layer.

11. The photovoltaic apparatus of claim 1, wherein the photoelectric conversion elements have a pin junction in such a manner that the first semiconductor layer having one conductivity type, an amorphous intrinsic semiconductor layer, and an amorphous second semiconductor layer of the other conductivity type having a wider optical band gap than the first

semiconductor layer does are arranged outward in this order.

12. The photovoltaic apparatus of claim 10, wherein the first semiconductor layer and the second semiconductor layer are made of n-type silicon and p-type amorphous SiC, respectively.

13. The photovoltaic apparatus of claim 12, wherein the n-type silicon of which the first semiconductor layer is made is n-type single-crystal silicon or n-type microcrystalline (μc) silicon.

14. A spherical semiconductor particles mass-producing apparatus comprising:

a crucible for storing a semiconductor;

heating means for heating and melting the semiconductor in the crucible;

a nozzle for dropping a molten semiconductor coming from the crucible; and

vibrating means for vibrating the molten semiconductor and thereby converting, in a vapor phase, the dropping molten semiconductor into spherical particles having uniform particle diameters.

15. The spherical semiconductor particles mass-producing apparatus of claim 14, further comprising:

means for pressuring the molten semiconductor in the

crucible.

16. The spherical semiconductor particles mass-producing apparatus of claim 15, wherein the pressurizing means is a gas source for supplying an inert gas having a pressure higher than atmospheric pressure to a space over the semiconductor in the crucible.

17. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein a pressure of a space with which an outlet of the nozzle communicates is selected to be lower than that of a space over the semiconductor in the crucible does.

18. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein a plurality of the nozzles are provided and each of the nozzles has an inner diameter of 1 ± 0.5 mm and a length of 1 mm to 100 mm.

19. The spherical semiconductor particles mass-producing apparatus of claim 18, wherein each of the nozzles has a length of 5 mm to 10 mm.

20. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the heating means comprises an induction heating coil provided in the vicinity of the crucible

and a high-frequency power source for energizing the induction heating coil.

21. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the heating means is resistive heating means for heating the crucible.

22. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the vibrating means has a vibration frequency of 10 Hz to 1 kHz.

23. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the vibrating means applies sound waves or ultrasonic waves to the dropping molten semiconductor and thereby vibrate the dropping molten semiconductor.

24. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the nozzle is vibratory, and the vibrating means vibrates the nozzle by reciprocating.

25. The spherical semiconductor particles mass-producing apparatus of claim 24, wherein the vibrating means drives the nozzle so that an outlet of the nozzle vibrates in a direction perpendicular to the axial line of the nozzle at an amplitude A that is smaller than $1/2$ of an outer diameter D1 of particles

to be formed.

26. The spherical semiconductor particles mass-producing apparatus of claim 24, wherein the vibrating means vibrates the nozzle along the axial line of the nozzle.

27. The spherical semiconductor particles mass-producing apparatus of claim 14, wherein the vibrating means is pressure varying means for varying a pressure of a space over the semiconductor in the crucible.

28. The spherical semiconductor particles mass-producing apparatus of claim 27, wherein the vibrating means comprising:
a diaphragm provided so as to communicate with the space over the semiconductor in the crucible, and
a driving source for reciprocating the diaphragm.

29. The spherical semiconductor particles mass-producing apparatus of claim 27, wherein the vibrating means comprising:
a driving chamber that is connected to the space over the semiconductor in the crucible, and
a driving source for oscillating a pressure inside the driving chamber.

30. The spherical semiconductor particles mass-producing

apparatus of claim 14, wherein the vibrating means vibrates the crucible.

31. The spherical semiconductor particles mass-producing apparatus of claim 14, further comprising:

Lorentz force generating means for exerting Lorentz force on the molten semiconductor dropping from the nozzle and thereby forming particles through a pinch effect of decreasing a cross-section of the molten semiconductor.

32. A spherical semiconductor particles mass-producing apparatus comprising:

a crucible for storing a semiconductor temporarily;
heating means for heating and melting the semiconductor in the crucible;

a nozzle for dropping a molten semiconductor coming from the crucible;

vibrating means for vibrating the molten semiconductor and thereby converting, in a vapor phase, the dropping molten semiconductor into spherical particles having uniform particle diameters; and

crystallizing means for heating liquid or solid particles dropping from the nozzle in the vapor phase to control a cooling rate thereof and thereby converting the particles into single-crystal or polycrystalline particles.

33. A spherical semiconductor particles mass-producing apparatus comprising:

a crucible for storing a semiconductor temporarily;
heating means for heating and melting the semiconductor in the crucible;

a nozzle for dropping a molten semiconductor coming from the crucible;

vibrating means for vibrating the molten semiconductor and thereby converting, in a vapor phase, the dropping molten semiconductor into spherical particles having uniform particle diameters;

crystallizing means for heating liquid or solid particles dropping from the nozzle in the vapor phase to control a cooling rate thereof and thereby converting the particles into single-crystal or polycrystalline particles; and

diffusing means for causing crystalline semiconductor particles of one conductivity type to pass through a passage in a material gas containing atoms or molecules with which the crystalline semiconductor particles are to be doped, and thereby forming a surface layer of the other conductivity type on each of the crystalline semiconductor particles.

34. A spherical semiconductor particles mass-producing apparatus comprising:

crystallizing means for heating liquid or solid particles existing in a vapor phase and thereby converting the particles into single-crystal or polycrystalline particles.

35. The spherical semiconductor particles mass-producing apparatus of claim 32 or 34, wherein the crystallizing means is a laser source for applying laser light to the particles.

36. The spherical semiconductor particles mass-producing apparatus of claim 32 or 34, wherein the crystallizing means is a radiation heat source provided adjacent to a passage of the particles, for heating the particles by radiation heat.

37. The spherical semiconductor particles mass-producing apparatus of claim 35, wherein the crystallizing means heats the particles so that the cooling rate of the particles has a gentle profile, to thereby prevent development of cracks in the particles and prevent the particles from becoming amorphous.

38. A spherical semiconductor particles mass-producing apparatus in which crystalline semiconductor particles of one conductivity type are passed through a passage in a material gas containing atoms or molecules with which the crystalline semiconductor particles are to be doped, to form a surface layer of the other conductivity type on each of the crystalline

semiconductor particles.

39. The spherical semiconductor particles mass-producing apparatus of claim 33, wherein the passage extends in a vertical direction and surface layer diffusion is performed as the crystalline semiconductor particles drop through the passage.

40. The spherical semiconductor particles mass-producing apparatus of claim 39, wherein the crystalline semiconductor particles on which a diffusion agent is deposited by passing through the passage are heated to form thereon a surface layer having a desired thickness.

41. The spherical semiconductor particles mass-producing apparatus of claim 33, wherein the semiconductor is silicon.

42. A photoelectric conversion element comprising:
a plurality of semiconductor layers formed by the mass-producing apparatus of claim 14.

43. A photovoltaic apparatus comprising:
a plurality of photoelectric conversion elements of claim 42.

44. A spherical semiconductor particles mass-producing

method comprising the steps of:

heating and melting a semiconductor;
dropping a molten semiconductor in a vapor phase; and
vibrating the molten semiconductor.

45. A spherical semiconductor particles mass-producing method comprising the step of:

heating and re-melting, in a vapor phase, dropping semiconductor particles and thereby converting the semiconductor particles into single-crystal or polycrystalline semiconductor particles.

46. The spherical semiconductor particles mass-producing method of claim 44, further comprising the step of:

performing diffusion in a gas containing a composition with which the single-crystal or polycrystalline semiconductor particles are to be doped.

47. The photovoltaic apparatus of claim 1, wherein the first semiconductor layer is a direct gap semiconductor layer.

48. The photovoltaic apparatus of claim 47, wherein the direct gap semiconductor layer is made of a semiconductor selected from the group consisting of InAs, GaSb, CuInSe₂, Cu(InGa)Se₂, CuInS, GaAs, InGaP, and CdTe.

49. The photovoltaic apparatus of claim 1, wherein a plurality of the supports each having peripheral portions extending outward are arranged adjacent to each other, and part of the first conductor in the peripheral portion of one support of each pair of supports adjacent to each other and part of the second conductor in the peripheral portion of the other are laid one on another and electrically connected to each other.

50. The photovoltaic apparatus of claim 49, wherein the peripheral portion has upward projections or downward projections, and the upward projection or downward projection of one support of each pair of supports adjacent to each other and the upward projection or downward projection of the other are brought into contact with and electrically connected to each other.